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LUNAR ATMOSPHERIC TIDES OVER CANADA.*

By Andrew Thomson.

ALTHOUGH it had been believed for thousands of years that the moon exerted influences on the weather, only within the last century have definite effects of the moon on the atmosphere been measured. The expected effect would be to create a tide in the film of air which surrounds the planet similar in many respects to the tides of the ocean. Many investigators, including Laplace, looked for atmospheric tides, but Lefroy, who later did much geophysical work in Canada, first determined in 1842 quantitatively the moon's effect from the barometer records obtained at the island of St. Helena. Dr. S. Chapman has recently determined the amplitude and times of these lunar tides at St. John, Montreal, Toronto, Vancouver and Victoria.† The tidal constants obtained at these stations find applications in terrestial magnetism, aurora and other lines of geophysical investigation. The theory of the atmospheric tide and the determination of the tide-producing forces are approximately the same as for the ocean tides and may be found in the works on this subject by Thomson, Rayleigh, Darwin, Hough and Doodson.

Method of Determining Magnitude of Atmospheric Tides.

Tides in the ocean are measured by the rise and fall of a float resting on the surface of the water but it is obvious that this method would be impossible to use to determine the ebb and flow of the

*Published by permission of J. Patterson, Director, Meteorological Service of Canada.

†*Q. J. R. Meteor. Soc.*, vol. 61, July, 1935, pp. 359-365.

atmosphere. The ocean tides could, however, be measured by changes in the weight of water above a submerged scale pan on the shore. When the tide comes in, the increase in the water over the scale pan could be accurately weighed and the height of the tide deduced.

This is essentially the method used to measure the atmospheric tide. The weight of the air column above a station to the outer limit of the atmosphere is measured by the barometer and is usually reported in Canada as the equivalent of the weight of a column of mercury so many inches high. If the tide in the atmosphere were large enough the variations could be seen from day to day as a regular fluctuation on the barograph. However as the daily range of the lunar tide from high to low at Toronto is only two thousandths (0.002) inch, special methods must be employed to determine such minute periodic fluctuations.

We may compute the lunar tide at any station where hourly values of the pressure are available for a long period of years. We begin by writing down the observed barometric pressure at the hour nearest to the lunar transit followed in a row by the succeeding 24-hourly values of pressure. We begin the second row directly below the first row with the hourly pressure nearest to the lunar transit on the next lunar day followed as before by the ensuing 24-hourly readings. This tabulation of pressures is maintained for as many days' data as are available. It is possible to obtain an approximate result with reduced labour by discarding those days when large fluctuations occurred produced by the passage of a front, thunderstorm or other irregularities. Usually days when the barometer range exceeds a certain limit are not included. The average value of the pressure at each hour from 0 to 24 hours is now obtained, and if deduced from a large number of days the average hourly values will be seen to fluctuate regularly, beginning with a high value of pressure nearest the hour of upper lunar transit and followed by a second maximum 12 hours later. It may be necessary, especially if a very long series of observations is not available, to make small corrections for the diurnal variation of pressures and its non-cyclic changes.

Dr. S. Chapman has employed a method similar to the above in computing the tides at Canadian stations but adapted to the Hollerith

tabulating machines. All days are included, regardless of the occurrence of pressure irregularities, the number varying from 11,276 days at Toronto to 4,226 days at Vancouver. The determination of the tides at the five Canadian stations entailed the tabulation of over 1,007,000 hourly values. It might be thought that greater accuracy would have been secured by taking values of 0.001 inch which were available for Toronto. This, however, is not correct as it is the natural non-periodic variations of pressure which render difficult the detection of the atmospheric tides.

Tidal Constants at Canadian Stations.

The lunar atmospheric tide, like the ocean tide, has two highs and two lows each day. Owing to the simple gravitational origin of the atmospheric tides, the highs occur very near the time the moon is highest in the sky and the lows when the moon is on the horizon. Dr. Chapman expresses the tidal constants in the notation of a harmonic series

$$C \sin (2t + \theta),$$

where t denotes time reckoned from the local hour of lunar transit at the rate of 360° per lunar day, and is given in microbars transformed here to units of one millionth of an inch. Table I summarizes the values for Canadian stations.

The tidal amplitude found at St. John, Montreal and Toronto is approximately 90×10^{-6} inch, which agrees with those found at Hamburg and at Greenwich. The amplitude at Vancouver, 6×10^{-6} inch, is very much the smallest tide so far computed, the next smallest being at Victoria. Dr. Chapman has suggested the proximity of a great mountain range or the ocean tides as a possible reason for the decreased amplitude, but the lunar atmospheric tide at Mexico City is 60×10^{-6} inch and this station is equally close to a great mountain. Along the British Columbia coast W. Bell Dawson has found the lunar influence small compared with the solar influence in ocean tides and the chief variation in the tidal difference is an annual one.†† The combination of forces which produce small lunar effects on the ocean tide at the straits of Georgia may also produce small lunar atmospheric tides.

††*Jour. Roy. Ast. Soc. of Canada,* vol. 1, 1907, p. 214.

At Victoria the lunar tide occurs 33 minutes before the lunar transit. This peculiar condition occurs at Hamburg and seven other stations out of a total of 30 stations. The cause of the early occurrence of the tide remains obscure but the reality of the occurrence is unquestioned as it is found at several stations where the data have been most accurately computed.

The seasonal variations in the atmospheric tides are quite pro-

TABLE I

Station	No. days observations	Season	Amplitude in. $\times 10^{-6}$	High tide − before + after lunar transit (minutes)
St. John	6,088	Annual	88	+14
Montreal	10,225	Annual	92	+35
	3,444	May-Aug.	122	+33
	3,416	Equinoctial	98	+27
	3,365	Nov.-Feb.	61	+54
Toronto	11,276	Annual	98	+23
	3,813	May-Aug.	132	+ 4
	3,737	Equinoctial	98	+39
	3,726	Nov.-Feb.	71	+37
Vancouver	4,226	Annual	6	+95
Victoria	10,591	Annual	18	−33

Table I. Atmospheric lunar tidal constants at Canadian stations. The single amplitude is given so that the range of the tide from ebb to high would be double this amount.

nounced at Toronto and Montreal, being almost twice as great during May to August as from November to February. This phenomenon occurs in both hemispheres, June tides being greater than January tides regardless of the fact that it is summer in one hemisphere and winter in the other. The tides from November to February occur 21 minutes later at Montreal and 33 minutes later at Toronto than the tides during May to August. This is also a world phenomenon that is found at most stations in northern and southern hemispheres.

The determination of the lunar tide gives a decisive answer to the age-old question of the moon's effect on the weather, since the distribution of pressure over any area controls the movements of air and the resulting weather for that area. The pressure changes associated with the passage of a low pressure centre or a "front" causes departures from the normal pressure of 0.2 to 0.5 inch. The total effect of the moon is shown in the tide which has a range from high to low of only 0.002 inch, less than one per cent. of the pressure fluctuation accompanying a change of weather. The average daily range of pressure from high to low at Toronto during February, 1935, was 0.25 inch and during August was 0.13 inch. Thus the average daily range due to all causes is roughly a hundred times greater than the fluctuation produced by the moon. Small as is the pressure due to the moon, it does produce an accompanying change of temperature on account of dynamic heating and cooling, which has been found from 62 years of observations at Batavia, Dutch East Indies, to amount to 3/100 degrees F. from hottest to coldest.

Although the moon's tide in the atmosphere does not affect the daily weather, there are good reasons for believing its effects are easily observable on the ionized layers found at 100 km. and higher. The earth's magnetic field goes through periodic daily changes due to movements of these ionized layers. When the Kennelly-Heaviside layer, the Appleton layer and other highly-conducting, less-permanent layers are mechanically moved up and down by the lunar tide, electromotive forces are set up which react on the earth's permanent magnetic field. About 97% of the magnetic field observed at the earth's surface may be considered due to a great magnet in its interior which sets up lines of force in the surrounding field. The cutting of these lines of force by the moving conducting layers, most especially the Kennelly-Heaviside layer, reacts on the earth's field and its effects are observed in the magnetic records as a small component with a period of a lunar day.

Krogness and Störmer have found the auroral frequency curve to have two sharp maxima at 100 km. and 106 km altitude. Egedal* has shown that when the aurorae are found at the higher altitude,

*On tides of the upper atmosphere. No. 10, *Publikationer fra det Danske Meteorologiske Institut*, Copenhagen.

it is at the time of high tide; and the aurorae occurring at the lower maximum are observed at the low atmospheric tide. This indicates that the layer of air most effective in producing the aurora is raised or lowered by the atmospheric tide. Egedal also showed from a statistical study of the meteor data since 1850 that the height at which meteors having a brightness equal to or greater than that of Jupiter varied in phase with the lunar tide. At high tide large meteors are first observed on the average at a height of 155 km., at low lunar tide at a height of 115 km. and the phase difference between the lunar tide and the curve for variation of the height of maximum frequency of first appearance of large meteors is only one-fifth of a lunar hour.

Some recent papers bearing on tides in the atmosphere are:

S. CHAPMAN, The lunar tide in the earth's atmosphere. *Proc. Roy. Soc.*, A 151, pp. 105-117, Aug. 1935.

S. CHAPMAN, Tides in the Atmosphere. *J. Lond. Math. Soc.*, vol. 7, pp. 68-80, 1932.

S. CHAPMAN, The world-wide oscillations of the atmosphere. *Beitr. Geophysik*, vol. 33, pp. 246-260, 1930.

J. BARTELS, Tides in the atmosphere, *Scientific Monthly*, vol. 35, pp. 110-130, Aug. 1932.

J. BARTELS, *Gezeitenschwingungen der Atmosphäre*, Wien-Harms Handbuch der Experimentalphysik, vol. 251, pp. 163-210, 1928.

THE APPROACHING DISAPPEARANCE OF SATURN'S RINGS*

By P. Muller.

THE observation of Saturn will present, in 1936 and the beginning of 1937, a very special interest; this is the epoch when, once again, we shall see its system of rings on edge. It is known that this phenomenon is produced twice in Saturn's year, that is to say, we are approaching the 23rd of its kind since the discovery of the ring by Galileo in 1610. It is useless to recall the disappointment of the latter when the rings disappeared a little later; all that is well known. The correct explanation of the phenomenon is due to Huygens and dates only from 1659. It was thus necessary to have four disappearances in order to deduce the periodicity and consequently the cause of the phenomenon. The result is briefly as follows (it will be sufficiently exact for an observer placed on the sun): the ring presents the same succession of aspects as the wing of a bird which passes before us at the height of the eyes but in this case the majestic "flapping" lasts 29 years.

It is possible to give a convenient scheme of the aspects of the ring under the following form. Remember, in the first place, that the ring, supposed opaque and very thin, disappears in three cases:

(1) If the earth is found in its plane its extreme thinness, when seen edgeways, renders it invisible;

(2) If the sun is found in its plane, the illumination is tangent (or grazing) and the ring disappears, whatever be its presentation;

(3) If the sun and the earth are found, one on one side, the other on the other side of this plane, we view the dark face.

This being agreed on, let us see how we can represent the phenomena. The elements which determine, at a given instant, the presentation of the ring are uniquely the angular height of the earth and of the sun above its plane; or rather, if you prefer, the perspective under which the ring is seen from each of the two bodies. The

*Translated from L'Astronomie for October, 1935. The author is assistant at the observatory at Strasbourg.

height of the earth determines what one calls the "aperture" of the ring, and the height of the sun its illumination. Hence we can predict easily the conditions of observations by representing these two elements, aperture and illumination, graphically as a function of the time. Before proceeding further I beg the reader to refer to Fig. 1, in which the quantities thus defined are represented by a curve extending throughout the last Saturnian year. The positive heights correspond to the north face of the ring.

It is to be remarked that the double curve thus obtained will resemble sufficiently nearly the apparent trajectory of the sun-earth system as seen by an observer placed on the ring so as to have it for

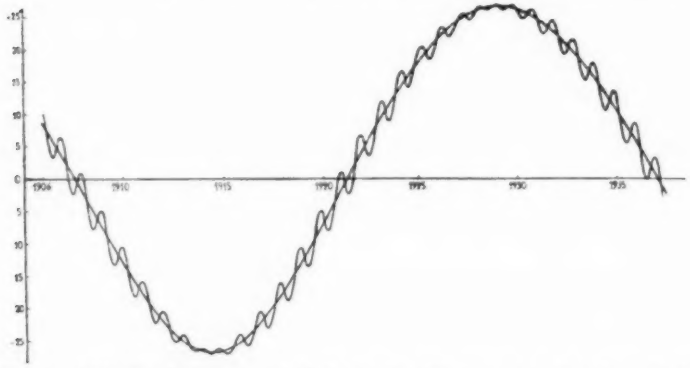

FIG. 1. Altitude of the sun and of the earth with respect to the plane of the rings. Variations during one Saturnian year.

The simple sine-curve refers to the sun, vertical heights above the horizontal line representing degrees north of the plane of the rings, distances below representing degrees below the plane of the rings. The short waves refer to the earth, its altitude being alternately greater and less than that of the sun in the course of a year.

his horizon and omitting consideration of its diurnal rotation. To him the sun rises at a certain point of this horizon, mounts to a maximum height of 26° 41′ (the inclination of the plane of the ring to that of the orbit of Saturn), then sets so as to descend as far below the horizon and then to rise anew. The earth gravitates a little distance about the sun in a series of sinusoids along the trajectory of

the sun, each of which corresponds to a terrestrial year. One can show that there is a longer time from a rising to a setting than the reverse. If, in effect, one considers the dates of the last passages of the sun through the plane of the ring since 1832 one finds intervals alternately of 5,000 and 5,740 days. This dissymmetry is due to the eccentricity of the orbit of Saturn; in effect, the ring passes through the sun when Saturn is found at one of the extremities of a chord parallel to the plane of the ring and passing through the sun, thus through the focus and not through the centre. This chord divides the orbit into two arcs of unequal lengths, traversed, with still greater reason, in unequal times by Saturn. There results this curious fact that on the average we see more often the north face of the ring and the north pole of the planet than the south face and the south pole. One can say, in the language of the statistician, that, ignoring entirely the date when one finds himself he could wager 6 to 5 that he would see the north face and pole.

Refer again to Figure 1. One sees that the phenomenon under consideration corresponds to the epochs where the curves approach the plane of the ring and traverse it. The drawing shows immediately why things are not so simple for the earth as for the sun, the former being able to pass several times into the plane of the ring at the time of a single passage of the sun. Let us add, without dwelling on it, that one can submit the question to calculation and that without difficulty one finds the following result: there is always either one or three consecutive passages of the earth, and the case of only one is the more rare.*

By way of illustration I have traced on a larger scale and with the aid of a greater number of points the curves corresponding to the interesting epochs since 1848, or for the last six passages of the sun (Fig. 2). One will find there the dates of the conjunctions (C) and oppositions (O) of Saturn, an element indispensable to take into consideration in the interpretation of our situation as terrestrial observers. From this one prepares a scheme, simple and complete,

*The number of these passages would attain the values 5, 7, 9 . . . etc. . . . if the earth, all other things being equal, would describe higher arches, which would take place for a great inclination of the orbit of Saturn to the ecliptic; but we know it amounts to hardly 2½°.

which indicates at every moment the illumination of the ring (height of the sun), its presentation (height of the earth) and the position of Saturn (situation with respect to O or C). Thus there leaps to the eye the fact that the phenomenon was practically unobservable in 1878, also that it was presented under the best conditions in 1848 (observations of the two Bonds at Harvard) and in 1907 (numerous observations, notably of Barnard and of Lowell). One will verify also that in the case of these six phenomena four have exhibited three passages of the earth through the plane of the rings and that this is the more frequent case.

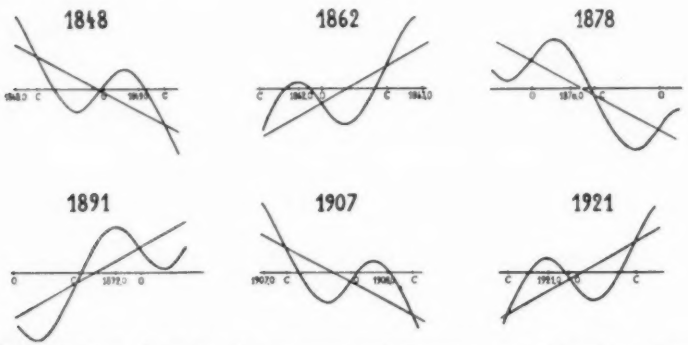

FIG. 2. Scheme of the last six phenomena of disappearance of the rings. The straight line refers to the sun, the curved line to the earth; C, conjunction; O, opposition.

Finally, and that in brief is the object of this study, I have traced the curves for the epoch of the approaching passages of the sun, on a still greater scale (Fig. 3). We see at once that it will constitute an interesting limiting case; the curve of the earth, instead of cutting three times, has two intersections confused in a tangent point, and the third follows much later. The tangence is so exact that the minimum of the heights, calculated by parabolic interpolation setting out from the table in the Almanac, is equal to 0° 0′ almost to the precision of the table. This turn of the curve signifies that we shall see the north face of the ring under incidences weaker and weaker to grazing incidence, then increasing anew; but it will always be

the north face, and it will be necessary to await the passage at the beginning of 1937 in order to see, this time for a new period of 13½ years, the south face.

Here then are the dates to remember:

Conjunction of Saturn with the sun	March 3, 1936
Western quadrature	June 13, 1936
First disappearance of the rings	June 30, 1936
Opposition	Sept. 12, 1936
Eastern quadrature	Dec. 8, 1936
Second disappearance of the rings	Dec. 29, 1936
Definitive reappearance	Feb. 21, 1937
Conjunction	March 16, 1937

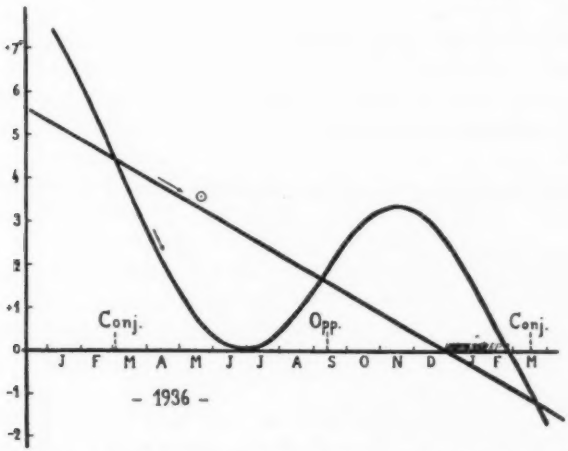

FIG. 3. Scheme of the phenomenon of the disappearance of the rings in 1936-37. Note that during the "shaded" period the earth is north of the rings, the sun below.

The circumstances will be moderately favourable. The first phenomenon will follow soon after western elongation, the second will occur entirely after eastern elongation. One can then expect to observe at dawn and in the twilight, and perhaps not to see the south face of the ring and the south pole of the planet before the

middle of the year 1937. The most interesting, but also the most difficult, observations will be during the period of continuous invisibility of the rings (the zone hatched-in on the diagram) when the sun will be below and the earth above the plane of the rings.

What are the observations to be made during such a phenomenon? It will be necessary to study particularly the famous condensations, more or less brilliant, which show themselves on the ansae, then dark, of the rings; to note their position, by a sketch as accurate as possible, or still better to measure the distances of their centres to that of the globe or to an edge. It will be very useful also to follow their appearance and disappearance setting out from the end of June, for it is not certain, far from it, that they will be visible permanently from June 30 to December 29. One will see them around these two dates, but within limits which it will be well to know. It is a simple question of visibility or non-visibility, which requires neither equatorial nor micrometer. One will endeavour, at the immediate proximity of the disappearances (which will be only a question of hours) to determine if the two ansae disappear at the same time or if on the contrary one can show itself without the other, as has already been observed, and when. Finally, as accessory observations, the epochs, as this approaches, of the eclipses, transits, immersions and emersions of the satellites, especially of Titan.

One sees that it will be worth the trouble, during the coming year, to direct the telescope toward the world of Saturn every time that the weather lends its aid—let us hope that it will be very often!

APPLICATIONS OF SPECTROSCOPY*

By Herbert Dingle

FOR a long time after Newton's original work on the subject the spectrum remained little more than a scientific curiosity. Then, about the middle of the nineteenth century, its possibilities suddenly dawned on chemists in a most dramatic manner. In 1860 Bunsen, who had had much experience in what spectrum analysis was possible at that time, saw some lines which he did not recognize in the spectrum of certain spring waters. With the perseverance characteristic of his countrymen he evaporated forty-four tons of this water and extracted about 200 grains of a new element, which he named *cæsium*. Here, then, was a practical use for the spectrum. Immediately the hunt for new elements became general, and in a short time the spectroscope had discovered rubidium, thallium, indium, and even helium in the sun, though it was not until 1895, when it appeared on the earth as well (again to the spectroscope) that the reality of this last discovery was generally acknowledged. In the meantime, gallium had been added to the list. Clearly chemistry had found a weapon of very great power.

It soon became evident, however, that this weapon was two-edged. The disturbing fact had to be faced that the spectrum of a substance varied with the means of excitation employed. The appearance of an unknown line turned out to be no criteron of the existence of an unknown element: there was the possibility that it came from a familiar substance in unfamiliar guise. Moreover, the spectrum did not always show all the elements which were known to be present. Common salt in a flame, for instance, showed sodium but not chlorine. The more, in fact, the spectrum was studied, the more numerous were the anomalies found. Chemists became suspicious of their new ally. Eventually the demand for its assistance fell off until at last it became almost completely neglected, and the study of spectra was given over to the physicists.

* Part of the third of a series of three Cantor Lectures on "Modern Spectroscopy" before the Royal Society of Arts and printed in the *Journal* of that Society, January and February, 1935. Published separately, price 2s. 6d.

Meanwhile, however, Kirchhoff and Bunsen, as we have seen, had discovered how to interpret the absorption spectra of the sun and the stars, and spectroscopy had been taken up by the astronomers with a zest little short of that previously shown by chemists. The same difficulties presented themselves, of course, but the astronomer was not, like the chemist, able to face them with an independent spirit: he could not abandon spectra without giving up astrophysics. The chemist could treat his material in various ways: he could handle it and weigh it, he could taste it if he wished, and smell it whether he wished or not. But the astronomer could do nothing with his stars except look at them, and if he refused to analyze their light he would be left helpless. He was forced, therefore, to carry on researches with an instrument he did not fully understand, and since the physicist—misled, as we now know, by a misapprehension of the laws of atomic mechanics—was powerless to help him to a true interpretation, it is not surprising that in some respects he went astray. It is only fair to record that when at last spectroscopy began to establish itself on a sound theoretical basis it was from astronomical sources that some of the most crucial data were obtained.

That occurred in 1913 when Bohr put forward his theory of the hydrogen atom, which was to be expanded later into the general theory of atomic structure which I have described. It is interesting to recall that that theory was originally conceived apart altogether from spectroscopy. The fundamental idea had arisen in Bohr's mind from quite other considerations, and he was seeking to give it adequate expression when the formula connecting the wave-lengths of the hydrogen lines, which had been an enigma since its discovery in 1885, was somewhat accidentally brought to his notice. Immediately he realized that here was the very essence of his theory in numerical form. Stellar observations, giving a much more extended hydrogen spectrum than was then obtainable in the laboratory, gave the theory credibility, to be strengthened to conviction by the astronomical observations of Pickering, the calculations of Rydberg, and the laboratory work of Fowler. From that moment spectroscopy took the leadership in physical progress, and for the next dozen years it led the way to an advance which, for rapidity and fundamental significance, is without parallel in scientific history.

The golden days of theoretical atomic spectroscopy are now over. It has given birth to a new mechanics and to a theory of molecules, and yields pride of place to its offspring. Quantum mechanics rules the deliberations of physicists, and band spectrum analysis those of physical chemists. But a new era is opening for it in practical application. To a degree never before approached, spectrum analysis in many and various forms is penetrating the world of industry, of medicine and of research. It is an interesting phenomenon, this resumption by chemists of a method given up in distrust so many years ago, but it is not a simple return of a penitent to a neglected duty; it is rather a rediscovery, by a greatly enlarged army, of a weapon which its forerunners were too ill-equipped to use with effect. Like the crew in *The Ancient Mariner*—

> 'Twas not those souls that fled in pain
> Which to their corses came again,
> But a troop of spirits blest.

I think it is not too early to say that when the final history of spectroscopy comes to be written, the present age, so far as atomic spectra are concerned, will appear as that in which the potentialities of the spectrograph as a universal scientific instrument began to be realized.

There is, of course, a reason for this, but the discovery of that reason is not a very simple matter. The obvious suggestion is that with the accumulation of experience and the growth of theoretical knowledge, the vagaries which frightened away chemists in the early days are now explicable and can be harnessed for practical ends; but this, I think, plays a very small, if any, part in the matter. There is not much sign that present-day applications utilize to an appreciable extent the theoretical knowledge which is available. I suspect the reason is to be found, first, in the fact that the urgency and multiform character of modern industrial problems calls for every means of attack within reach; and secondly, in the achievements of instrument manufacturers, who, responding to the great demand of physicists for spectrographic apparatus in the years following the advent of the Bohr theory, have developed the technique of its construction for various purposes to such a degree as almost to compel recognition of its industrial importance. Slightly to alter Shake-

speare, we may say that the means to do good deeds makes good deeds done.

The Stellar Spectrum Sequence

We could spend a profitable hour considering almost any of these applications of spectroscopy, and I have to touch in some measure on them all. Let me begin what must obviously be a mere sketch, with the problems of astronomy. We have seen that the spectrum of a star depends on the composition of its atmosphere. In the first naïve deductions that were made it was assumed that it depended on nothing else, and accordingly the variations of stellar spectra were taken to indicate variations of stellar composition. It soon became evident that nearly all stellar spectra could be arranged in a regular succession of types, between which the transition was gradual. (See any modern text on astronomy.) The general trend of the sequence is from simple spectra, showing mainly hydrogen, to complex spectra in which, first, many metallic elements, and later, compounds appear. Here, apparently, was evidence of an evolution of chemical elements. The youngest stars were formed mainly of hydrogen, the simplest element, and the course of evolution, as in the organic world, was that of increasing complexity.

Since space will not permit further reference to this fascinating subject, it may simply be said here that the realization that these spectrum differences are due chiefly, if not entirely, to differences of physical condition and not of chemical composition, has restored to astronomers the conviction that what they are studying in this matter is astronomy and not chemistry—the evolution of stars and not that of elements. The theory of stellar evolution, however, is at present in the melting-pot, and it would scarcely add to our comfort to follow it here.

The Doppler Effect

I must hasten, however, to correct the impression, if I have given it, that early spectroscopic astronomy was based entirely on misinterpretation. One of the earliest applications of the spectroscope to the heavenly bodies is still one of the most important, and

indeed, one need only reflect for a moment on the present state of physical astronomy to realize how vital it is. I refer to what is known as the Doppler effect—the determination of the speed of approach or recession of a body, from a measurement of its spectrum. If a source of light is approaching an observer the light waves are effectively compressed and therefore shortened, while if it is receding the opposite effect takes place. This shows itself as a displacement of all the spectrum lines towards the shorter or longer wave-lengths, respectively, and it can be shown that the amount of the displacement is approximately proportional to the speed of motion. (If the body is not moving directly in the line of sight, the component of motion in this direction determines the displacement.)

The effect is small, but celestial motions are large, and in this way we can deal with such widely differing problems as the measurement of the velocities of stars, the speeds of the sun's and planets' rotations, the motion of the components of double stars which otherwise would not be recognized as double at all, and the determination of the structure of Saturn's rings. From such observations it has lately been discovered that the whole stellar system is rotating—or rather that its separate units are independently revolving round a centre, for a rigid rotation of the whole system would hardly be observable without reference to external systems. It is this effect, too, which forms the whole of the observational basis of the theory of the expanding universe.

Empirical Relations Between Spectra and Other Stellar Phenomena

The absence of a physical theory of spectra did not prevent astronomers from making empirical deductions by correlating the spectrum sequence with other stellar characteristics. For instance, when the stars were arranged in order of spectral type it appeared that they were also arranged in order of velocity: the more complex the spectrum, the faster the star moved. On the view that complexity grew with age, this meant that a star gained speed with age—a very difficult thing to understand. It now appears that this is probably the final effect of a number of independent correlations. The simpler spectra are those of bright stars (i.e., absolutely bright

stars, not merely those which appear bright because they are near), and bright stars are massive stars. The observation in question, then, is that the more massive a star is, the slower it moves—quite an intelligible result, indicating that there is, at least approximately, a condition of equipartition of energy among the stars of our system.

The direct correlation of spectral type with absolute brightness was also very significant. It showed that the stars lay along two branches, in one of which the brightness was approximately constant for all spectral types, while in the other the brightness decreased steadily as the type advanced. The two branches joined at the simplest type. The order of increasing complexity in spectral type is indicated by the letters B, A, F, G, K, M, and, quite arbitrarily, B stars are said to be "early" and M stars of "late" type. The relation in question, then, meant that stars of early type were all bright, while those of later type fell into two classes of brightness, the gap between which increased with advance of type.

This provided a means of determining the approximate distance of a star. This sounds mysterious, but it comes about in the following way. The relation shows that by examining the spectrum of a star we can approximately determine its absolute brightness—definitely with the early types but ambiguously with later ones, for they have two possible brightnesses for each type. Now it is easy to measure how bright a star *appears*, and hence, knowing how bright it actually *is*, we can at once calculate the distance necessary to reduce the actual to the apparent brightness.

There seems at first no way of removing the ambiguity with the later types: we can determine two possible distances, but cannot, apparently, choose between them. Here again, however, the spectroscope comes to our assistance. Close examination shows that spectra, at first grouped together in the same type, show minute differences which distinguish the high from the low luminosities. These differences are found in the relative strengths of neutral and enhanced lines. We shall see the reason for this difference presently; for the moment we will simply observe that, on purely empirical grounds, we can find the distance of a star from its spectrum.

Stellar Spectra and Physical Theory

So far astronomers had got along without help from physical theory, merely by comparing observations in the sky and in the laboratory with one another. With the rise of the Bohr theory a new era began for this work. What was previously vague became precise, and general description gave place to detailed calculation. The early assumption, that spectrum differences denoted only chemical differences, had, it is true, yielded to laboratory experience; it had been recognized that physical conditions had something to do with the matter, and to a few pioneers, such as Lockyer, it was apparent that of such conditions temperature was one of the chief. But what theory alone could indicate was the precise character and extent of the various physical modifications of spectra. Without going into details we may say that it is now fairly probable that, so far as chemical composition is concerned, stars are almost identical with one another and with the earth (except for a possible superabundance of hydrogen), and that the physical conditions most potent in determining the character of a stellar spectrum are temperature and density.

Let us recall our atomic model. The higher the temperature, the more is the energy available to remove electrons to outer orbits and ultimately to ionize the atoms, so that with increase of temperature we should see neutral giving place to enhanced lines, and these in turn to lines corresponding to further degrees of ionization of the atoms. But density steps in to modify this progression. When an atom loses an electron it can give its enhanced spectrum, but it does not remain permanently ionized. As soon as it meets an electron it returns to the neutral condition and radiates its former spectrum again. Now if the density is high there will be a good chance of such a meeting taking place, whereas if the density is low, the chance is small. Consequently, for a given temperature, corresponding to a given rate of ionization, there will be a rate of re-neutralization depending on the density; so that after a time, even at a fairly low temperature, most of the atoms will become ionized if the density is sufficiently low, whereas, even at a fairly high temperature, the degree of ionization will be kept down by rapid re-neutralization if

the density is sufficiently high. High temperature and low density, then, favour the appearance of enhanced lines, while low temperature and high density favour the appearance of neutral lines.

The effects of the two conditions can be disentangled. Without going into mathematical details we may say that, under the conditions usual in stars, temperature has the dominant effect and density causes relatively small modifications. Let us now recall our spectroscopic criterion for distinguishing the two kinds of star having the same spectral type. The spectral type, as a whole, is determined by temperature; hence the sequence B . . . . M denotes primarily a temperature sequence. At any given place in this sequence, however, density comes in to affect, in a minor way, the relative strengths of neutral and enhanced lines. We draw the conclusion that the star showing the stronger enhanced lines has the lower atmospheric density.

Now, this effect is precisely the criterion which, as we have seen, distinguishes bright from faint stars of the same spectral type. We can easily see why it provides such a distinction. Imagine two stars having, to the first approximation, similar masses, but one of which is swollen up to a much greater volume than the other. If the stars have the same temperature they will have the same brightness per unit surface area. The larger one, therefore, having the bigger surface, will radiate more light, and will appear the brighter star. It will also have a smaller density, for the same quantity of matter will occupy a larger volume; its spectrum will therefore show relatively strong enhanced lines. The two types of stars are known respectively as "giants" and "dwarfs".

The Galactic Nebular Lines

From among the many other applications of spectrum theory to the stellar system I select one—the problem of the galactic nebulæ. Many of these bodies give simple emission spectra showing the presence of hydrogen and helium, the lightest two elements, and including some strong lines which have never been seen in the laboratory. In the early days the explanation, of course, seemed obvious: there was an element (or perhaps more than one), which was named

nebulium, which had not been discovered on the earth, and there were indications that it was a light element. But the facts of atomic physics gradually made it appear unlikely that any light element was left to be discovered; and, moreover, the growing realization that spectra owed at least as much to physical condition as to chemical composition increased the probability that nebulium was a familiar substance (or substances) excited under novel conditions. A few years ago the explanation was given by Bowen. Analysis of known spectra enables us to determine the various orbits possible to the atomic electrons in different types of atom and, as we have seen, the spectrum lines correspond to the energy radiated when an electron changes orbit. Now it appears that, for some reason, when an electron is in a given orbit it is not equally willing to fall to any of the smaller ones available. It has certain preferences, and some transitions are so disliked that only very rarely are they chosen, and then only after considerable hesitation. The result is that in the laboratory the lines corresponding to such transitions are so feeble that they escape observation. In order to see them we should have to reduce the density of the gas very greatly, otherwise collisions with other atoms would knock the electron elsewhere while it was making up its mind to take the unfamiliar plunge. But such a reduction of density leaves us with very few atoms, and therefore reduces the strength of the total radiation. We can give the atoms time to make the decision only by greatly reducing the number allowed to make it. The consequence is that we have not been able in our laboratories to produce detectable radiations of this kind. But in the nebulæ these limitations are removed. The densities are extremely low, so that collisions are rare, and, at the same time, a nebula has volume enough to accommodate millions of stars larger than the sun, so there is no lack of atoms. Accordingly, we get sufficient of the unaccustomed radiation to make detection possible.

Now it does not follow, of course, that because transitions between particular orbits are rare, these orbits cannot be detected in the laboratory. There may be—and, in fact, always are—other orbits from which electrons move very readily to either of them, so that their energy values can be precisely determined from laboratory observations, and the frequency corresponding to the rare transitions

can be calculated. Such calculation show that the unknown nebular lines are due almost wholly to oxygen and nitrogen in various stages of ionization. Nebulium has become a myth, like phlogiston and caloric and other inventions of the past.

The Spectroheliograph and Solar Meteorology

Let us turn from the nebulæ to our sun—a star which, on account of its nearness, gives unique opportunities for detailed examination. You will remember that, in speaking of the absorption spectra of luminous bodies, I pointed out that the light in the absorption line was characteristic of processes occurring in the absorbing substance. This has been turned to account in examining the atmosphere of the sun. The instrument used for this purpose is known as the *spectroheliograph*. It consists of an ordinary spectrograph with a second slit placed over the absorption line in question so that only the light in that line passes through. An image of the sun is made to pass at a constant rate across the primary slit of the instrument while a photographic plate moves at exactly the same rate across the second slit. Since the spectrum line, being an image of the first slit, will in this case be an image of that portion of the sun which, at the instant considered, is portrayed on that slit, and since, as we have seen, it will be an image in the atmospheric light alone, the final picture on the plate, when the image of the whole sun has passed across the instrument, will be a photograph of the sun's atmosphere in the light of the particular spectrum line chosen for examination: that is to say, it will be a picture of the distribution of the atoms radiating that line in the atmosphere of the sun. The effect will be the same as if we could go to the sun, put an opaque screen at the bottom of the atmosphere, take away from the atmosphere all the atoms except those radiating the line in which we are interested, and then come back to the earth and take a photograph.

Studies of this kind, combined with Doppler displacement measurements and theoretical and other estimates of temperature and density, enable us to construct a solar meteorology in considerable detail. We can determine not only the horizontal but also the vertical distribution of elements in the atmosphere, and detect local

disturbances, cyclonic and otherwise, as well as general "winds". We can examine in particular the motions of the vapours in the neighbourhood of sun-spots and form a general idea of the character of those interesting phenomena. More detailed investigation reveals spectroscopic evidence of magnetic fields, not only in sun-spots but also over the general surface of the sun. It is scarcely too much to say that the spectroheliograph, if we know how to use it to the best advantage and properly to interpret the results, is capable of giving us all the information we require for a complete knowledge of the physical state of the sun's atmosphere.

Contours of Spectrum Lines

I ought not to leave the subject of astronomy without mentioning another refinement of observation which gives promise of fruitful application in the future. I refer to studies of the "contours" of spectrum lines—that is, the distribution of intensity across a line. No line is perfectly monochromatic: even the sharpest line is really a very short patch of continuous spectrum with a maximum intensity at a certain wave-length and a falling off of intensity at a definite rate on either side. Instruments known as microphotometers are now available for recording the intensity at each wave-length in a line. It appears that the total breadth, the ratio of intensity at specific points, and the degree and kind of asymmetry of the lines are all important criteria of particular physical conditions—such as the total number of atoms in the atmosphere engaged in absorbing the lines, and the rotation of the star on its axis—phenomena quite beyond any other conceivable means of investigation.

(In the rest of the lecture Professor Dingle referred to the determination of the metre and the yard in terms of a specified wave-length of light, qualitative industrial applications of spectroscopy, plant analysis, spectra and atmospheric pollution, spectra and the purity of milk and quantitative spectrum analysis.)

EDWIN BRANT FROST, 1866-1935*

By Frank Schlesinger

EDWIN BRANT FROST was born on July 14, 1866, at the pleasant town of Brattleboro in the southeastern corner of Vermont. Edwin was graduated A.B. at Dartmouth in 1886. The year following, he continued postgraduate work at Dartmouth, taught school in a nearby village, and at the end of the year spent a few months at Princeton, where he came under the influence of Charles Augustus Young (1834-1908), then perhaps the leading teacher of astronomy in this country. An appointment to an instructorship at Dartmouth came in 1887. At that time advanced work in astronomy and in almost every other branch of science meant a year or more in Europe. Accordingly, Frost secured a two-year leave (1890-1892) to visit most of the European observatories and to spend the second year at Potsdam in Germany, where Vogel was establishing an observatory devoted especially to the new science of astrophysics and where he had gathered around him an exceptionally brilliant staff, all of them leaders in their chosen fields: Scheiner, Müller, Kempf, Wilsing, Hartmann, Ludendorff, Eberhard, Lohse. Frost thus had an opportunity to come into contact with a group that it would have been difficult to match at a single institution, either in that day or during the twenty years to follow. When he returned to Dartmouth in 1892 it was as assistant professor, and this promotion was followed in 1895 (when he was only twenty-nine years of age) by a full professorship and the directorship of the Dartmouth Observatory.

While at Potsdam Frost made arrangements with Scheiner to translate into English the latter's *Spektralanalyse der Gestirne* (1891). Frost's work appeared in 1894. It is more than a translation, for although there were only three or four years between the two books, much progress had been made in astronomical spectroscopy in the interval, and Frost brought the book up to date, besides

*Slightly abbreviated from the sketch by Professor Schlesinger, of Yale Observatory, in *Science* for June 21, 1935. A new book by the late Professor Frost, entitled *Let's Look at the Stars*, is just announced.—*Editor.*

incorporating some new matter in the form of tables. Frost's book played an important part in the rapid development of the science in this country, and until very recently it remained the standard work on the subject in English.

The lines along which Frost's career was likely to develop must have seemed unusually clear to him at this time, and doubtless he looked forward to a long term of usefulness to his alma mater. But a series of apparently remote events rapidly and completely changed his outlook. James Edward Keeler (1857-1900) had left the Lick Observatory in 1892 to take charge of the Allegheny Observatory in Pittsburgh. There he at once made a striking series of spectroscopic observations with the meagre equipment at his disposal. One effect of this success was to give great impetus to a movement to erect a new Allegheny Observatory, with a 30-inch refractor as its principal instrument. When something more than half of the amount of the money necessary for this project had been raised, business conditions in Pittsburgh caused the fund to halt, and Keeler had to look forward to some additional years with the old equipment. Those were the days when Catherine Bruce, of New York City, was devoting a good deal of her income to further astronomical research in all quarters of the globe. In 1897 Dr. George E. Hale, director of the recently completed Yerkes Observatory at Williams Bay, Wisconsin, successfully applied to Miss Bruce for a grant sufficient to bring Keeler to the Yerkes Observatory for five years and to set on foot an extensive programme of spectroscopic observations of the stars. He was to go to Yerkes in the summer of 1898, but in the spring of that year he received a most unexpected call to succeed Holden as director of the Lick Observatory. In common with everyone else concerned, he felt that he could not refuse this call. For the place thus left open at the Yerkes Observatory Dr. Hale naturally turned to Professor Frost, who took up his duties at Williams Bay in the summer of 1898, expecting to stay for five years only. But before the end of this term the outlook had again changed, for Hale had been organizing what was at first an expedition from the Yerkes Observatory to California to observe the sun under more favourable climatic conditions. As everyone knows, this expedition grew into the Mount Wilson Observatory. In the two years following 1903

much of the responsibility for the conduct of the Yerkes Observatory fell to Frost. On Hale's resignation as director in 1905, Frost was appointed to succeed him in June of that year.

Frost persisted in devoting his energies to the spectroscopy of "early-type" stars, to the practical exclusion of every other subject. Primarily for this purpose the Bruce spectrograph was constructed in 1900, largely from his specifications and under his supervision. With this instrument and with the able collaboration of Walter S. Adams, now director of the Mount Wilson Observatory, he measured the radial velocities of many "helium stars" or "Orion stars", as they were then called (now they are more logically designated as B-stars, following the Draper classification), and discovered their most important characteristics. It was shown that their space-velocities are small as compared with those of later-type stars and that there is a slight but unmistakable tendency for these stars to recede from our system as a whole, as if they formed an expanding group. These facts were later more fully developed by Campbell; their explanation is closely interwoven with recent important discoveries in astronomy and physics.

Frost also showed from changes in radial velocity that a surprising number of B-type stars are close binary systems, perhaps as many as one in every three. On several occasions I have witnessed his discovery of such a binary from a single photograph of its spectrum. This sounds like an impossibility, but the explanation is simple. Even in those days (around 1904) he was extremely nearsighted, and could see well an object not more than an inch from his eye; thus, as he used to say, by simply pushing his glasses up he always had at his disposal a magnifying power of about ten diameters. After he had secured a spectrogram, and developed it next morning, he would examine it in this way, sometimes before it was dry. If he saw the lines considerably displaced from their normal positions, he knew that it was extremely unlikely that this was because of the star's large space velocity, since, as we have said, he had found that such velocities are always small for B-type stars; the displacements must then be due to orbital motion, and so indeed they invariably proved to be when later he could examine a series of plates of that star.

Frost's place in astronomy is not to be judged on the basis of his researches alone. We have already mentioned his translation of Scheiner's work and the part this translation played. For more than thirty years his was the chief responsibility for editing the *Astrophysical Journal*, "an international review of spectroscopy and astronomical physics", founded in 1895 by Hale and Keeler, and now in its eighty-first semi-annual volume.

The last years of his life form a sad story, but an inspiring one as well. From early childhood he had had trouble with his eyes. This became acute in 1907 and necessitated long periods of complete rest for his eyes. In 1915 the retina in one eye became detached and within a few months he completely lost the sight in this eye. A few years later a cataract began to form in his other eye and grew worse and worse until he became totally blind. In spite of this heavy handicap, he managed for several years to continue his work as director of the observatory, but finally felt compelled to retire in 1933.

In the first year of his retirement he dictated to his wife, and dedicated to her, his autobiography, under the title *An Astronomer's Life* (Houghton Mifflin Co.). This volume is important as a contribution to the history of present-day science. His story is told with fascinating charm, and I for one found it impossible to put it down before I had finished it. It is much more than a setting down of facts or a collection of well-told stories. As a record of courage and good sportsmanship in the face of one of life's severest disasters it cannot fail to move every reader. In all his years of complete darkness he never lost his sense of humour. To the last he had a way of ignoring his blindness in conversation and whimsically using terms and expressions that one should ordinarily expect only from those who can see.

Early in April (1935) Frost went to a Chicago hospital for observation. The cause of his ailment was diagnosed as gallstones. After some hesitation on account of his age (he was in his sixty-ninth year), an operation was performed on May 6. His condition improved for a few days but then his strength waned until the end came on May 12.

Among the honours which came to him were honorary degrees from Dartmouth and Cambridge; membership in the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences; honorary membership or its equivalent in the Royal Astronomical Society (London), Società degli Spettroscopisti Italiani and in astronomical societies in Mexico, Canada and Russia.

Dr. Frost was married in 1896 to Mary Hazard, of Boston; she and their three children survive him, as does his elder brother, who, like their father before him, is a professor in the Dartmouth Medical School.

Yale University Observatory.

THE UPPER ATMOSPHERE.

By E. G. Hogg*

TWO factors have combined during recent years to bring into prominence the question of the nature and structure of our atmosphere—one in the study of the conditions under which wireless waves are transmitted and reflected; the other is the nature and origin of the cosmical rays which bombard the earth's surface in all directions. These researches have made it only too clear that our gaseous envelope possesses a most complex structure, and it may not be out of place to give our readers a brief account of what has been discovered in this fascinating matter.

We were taught to believe that our atmosphere was a simple layer, mainly composed of two transparent gases—oxygen and nitrogen, in which both temperature and pressure decreased as we passed outwards through it. Suspended in this layer was a large supply of water vapour, visible to us in part in the form of clouds. We shall best approach the subject by regarding the atmosphere as a series of layers, each of which has its own special features and characteristics.

The first layer enwrapping the earth is the "troposphere"—the sphere of change. Its thickness varies from 5 to 10 miles at different times and places, and it contains nearly 90 per cent. of the total substance of the atmosphere. It is for the most part in a state of agitation by winds and storms, whereby its contents are kept thoroughly mixed. The water-vapour of the atmosphere is practically confined to the troposphere; the curious clouds which reach the greatest height above the earth's surface mark the upward limit of the troposphere. The temperature in this elevated part may be as low as 60 degrees below zero Fahrenheit.

The Stratosphere

Passing outwards we come into the stratosphere—a region characterised by almost perfect calm; storms do not reach so high.

*In *The Press*, Christchurch, N.Z.

As we rose through the troposphere we found that the temperature gradually fell, but, strange to say, as we proceed through the stratosphere the temperature remains almost constant from about seven to 23 miles and then begins to rise slightly with increasing height. In the lower part of the stratosphere is a layer of ozone which rarely extends to a height greater than 25 miles from the ground. Its distance from the earth, which varies with the position of the sun, averages about 15 miles. This layer plays a very important part in stopping a large amount of the ultra-violet radiation from the sun. It would appear that the amount of ozone is extraordinarily small, as, according to Jeans, its total weight is only that of a sheet of paper about a two-thousandth of an inch in thickness—the thinnest of tissue paper. A considerable amount of solar radiation in the red and infra-red parts of the spectrum is absorbed by the oxygen, water-vapour, and carbon dioxide present in the troposphere.

Wireless Waves

In the early days of radio transmission some perplexity arose when it was found that experimenters could pick up messages from very distant stations without any difficulty. The waves, instead of travelling as was anticipated in straight lines, had in some fashion been bent round. It was surmised that a beam when it reached a certain height above the earth's surface must have been reflected back to the earth. The difficulty, of course, was as to the mirror which caused the reflection to take place. Now, quicksilver reflects light because its surface is a conductor of electricity, and as air and other gases can conduct electricity under certain conditions, it is reasonable to suppose that the mirror which reflects the wireless waves may be composed of air or gas in a certain condition. Generally speaking, gases can conduct electricity when they are "ionized", i.e., when some of the electrons have been torn from the atomic nucleus, and so are free to move about and carry electricity or transport an electric current.

The Reflecting Layers

In 1902, two scientists, Heaviside, in England, and Kennelly, in the United States, independently of each other, suggested that

in the higher reaches of the atmosphere there must be a layer of ionized gas which reflects earthwards the radio waves falling upon it. This conjecture has been amply confirmed, and this layer is now known as *E* or the Heaviside-Kennelly layer. It is usually located at a height of 65 or 70 miles above the earth's surface, though it may be as near as 45 miles or as distant as 90 miles.

Subsequent research has shown that below this layer is another one, *D*, lying only 25 or 30 miles from the ground, which is specially active in the early morning, trapping long radio waves and reflecting them back to the earth. Beyond the *E* layer lies another, the *F* or Appleton layer, whose height varies from 90 to 250 miles above the earth. Some of the waves falling on the layers *D* and *E* are not reflected there, but pass through only to be intercepted by the *F* layer and sent back to the earth.

Now that the existence of these layers has been demonstrated, it is easy to understand what difficulties stand in the way of communicating with our planetary neighbours with wireless waves, as has been suggested. We do not say that the three layers cut off from outside space all the waves which fall upon them, but it is generally believed that only a small percentage of the waves with which we can experiment fail to get sent back to the earth and any message sent, say, to Mars would be mutilated beyond recognition before it got clear of the earth's atmosphere. It will help us in a measure to understand how there can be so many reflecting layers when we recall that the atmosphere is a mixture of many gases whose constituents may be "ionized" at different heights, and that ionization may be produced by different agencies which do not all operate at the same level above the earth's surface. Ultra-violet light is regarded as the most potent agent in causing ionization, though electrified particles ejected from the sun may play an important part in the process. There is undoubtedly a connexion between the emission of these particles and the occurrence of auroras.

Colour of the Sky

Another interesting phenomenon which occurs when we pass through the troposphere, and enter the stratosphere and that is the change in colour of the sky. As we ascend the density of the air

diminishes, i.e., it contains fewer and fewer particles to scatter and reflect the solar light. In January, 1934, the U.S.S.R. balloon "Stratosphere" ascended to a height of 13.64 miles above the ground and the observers recorded the following changes of colour of the sky as they ascended. At the height of 5.27 miles, they report sky blue; at 6.82 miles it is dark blue; at 8.06 miles dark violet; at 13.02, black violet, and at 13.64 miles black grey and, as Jeans says, there is no doubt that if we could ever get entirely outside our atmosphere the sky would look completely black.

The study of the stratosphere is yet in its infancy, but enough has been learnt of it to show that it contains many fascinating problems yet to be unravelled. Exploration by specially constructed balloons, carrying highly trained observers with delicate instruments, is the work which will engage an increasing number of scientists in the future and the day may yet come when, owing to the almost complete stillness of such atmosphere as there is in the lower parts of the stratosphere, long-distance flights in suitably sealed machines, will be made there instead of in the troposphere with its disturbed atmospheric conditions.

Since the above was written, there has appeared in the issue of "The Press" of August 29, an interesting cable informing us that Professor Appleton has been led by his researches into the structure and properties of the upper atmosphere, to the conclusion that the temperature in the stratosphere, which was known to rise as the distance from the earth increases, reaches in one of the enveloping layers the astounding figure of 1000 degrees Centigrade, and that this layer possesses properties which appear to destroy the possibility of utilizing extremely short waves for the transmission of wireless signals. The full import of Professor Appleton's discovery cannot as yet be measured, but his high standing in the scientific world and the success of his earlier work on the stratosphere give good ground for expecting that his conclusions will be confirmed by independent workers and that a very valuable addition has been made to our knowledge of this complex subject.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

The Value of Amateur Meteor Observation

The writer has frequently been asked if meteor observations made by amateurs are of any real value to science. The feeling often seems present that anything the amateur can do will be duplicated in a much more efficient and exact manner by the professional astronomer and that hence the amateur is really only observing for his own amusement. Though this may be true in some branches of astronomy it is most certainly not the case in meteor observations. Of course, it cannot be denied that someone who has spent a large number of hours in making visual meteor records will have attained a certain facility in noting the most important data and will therefore attain greater accuracy than one who is observing for the first time. But the ability to make good meteor observations does not depend on the rating of the observer in the astronomical profession and it is quite possible for the experienced amateur to outclass the inexperienced professional. It is also true that a great proportion of meteoric data can only be gathered visually, and without optical aid, which fact serves still further to emphasize the importance of the amateur in this field.

It must be remembered that we are now fairly certain that a vast substratum of meteoric debris exists throughout our whole stellar system. In view of this fact it is evident that a detailed study of this fragmentary material is of immense cosmological importance. During the past two years an increasing number of volunteers have assisted in visual meteor observations in various parts of Canada. The writer proposes to indicate briefly some of the many uses to which such observations may be put.

Let us assume that the following information has been recorded: (1) the time of the appearance of the meteor, noted to the nearest second; (2) its estimated magnitude or brightness; (3) the duration of a persistent train where present; and (4) any marked colour or other peculiarities. Suppose also that the majority of meteors observed are plotted. What results can be derived from these records?

In the first place the number of meteors alone, for any given time interval, leads to a calculation of the density of meteoric material in the region of space through which the earth is passing. From the plotted paths meteors belonging to a certain group, such as the Leonids or Perseids, may be separated from the others and the density of this particular swarm calculated. Of course only a small fraction of all the meteors encountered by the earth is visible to any one observing group and unless this group is large many of these meteors are missed, but allowance can be made for both these facts. A knowledge of the relative numbers of meteors appearing at different hours of the night and at different times of the year tells us much concerning their general motions and makes it possible to compute the average speed of these objects since the earth, moving through meteors with very slow random motions, will encounter many more on its preceding hemisphere. This effect will be much diminished in the case of meteors whose average velocity greatly exceeds that of the earth.

From the plots also may be determined the so-called radiant points of various groups of meteors. The radiant point marks the direction in space from which a group has come and this direction, coupled with a determination of the velocity of the meteors, makes possible the determination of their orbit about the sun. A study of the magnitude distribution, that is the relative number of meteors of various brightnesses, indicates the percentage of meteors beyond the visual range and also the relative numbers of masses of various sizes. The first fact is necessary in computing the total amount of meteoric material present in space and the second has a definite bearing on theories of the origin of this matter. Analysis of the frequency distribution of the time intervals between successive meteors of a particular swarm assists in a dynamical study of the past history of the swarm and thus, indirectly, gives information concerning its age. A correlation of the duration of persistent trains with the brightness of the meteors helps in the physical study of this very puzzling phenomenon. There is already some evidence that the colours of meteors bear some relation to their chemical composition, among other things. Careful records of meteor colours may prove to be increasingly valuable in the future. The relative numbers of meteors appearing at different angular distances from any one radiant may

give us an indication of the spatial distribution of luminosity in the meteor path itself.

All the above investigations may be carried out with the observations from a single station. Where, however, we have two or more stations located within from 20 to 100 miles of each other, the value of the results is greatly enhanced. Now, through triangulation, the heights may be obtained for all meteors observed at more than a single station. This makes it possible to apply all the observational data to a study of the earth's upper atmosphere. The height of a meteor's appearance and disappearance will depend not only on its velocity, mass, and composition, but also on the density, temperature, and composition of our atmosphere. Because of this the detailed study of meteors is inevitably associated with the study of the upper atmosphere.

What has been said so far applies to observations of the average meteor. The appearance of an unusually bright fireball often provides much additional information. A long enduring persistent train usually shows rapid motion and change of form. This, if carefully observed, reveals the currents in the upper atmosphere and the laws governing the diffusion of the train luminosity. Variegated colours in the head of such a meteor, in addition to any colour changes, should be accurately recorded because of their importance in a physical investigation of meteor luminosity. A deviation from a straight path gives information concerning the shape of the meteoric particle itself. The nature and region of audibility of sounds heard in connection with the appearance of a great meteor are closely related to the physical and dynamical state of the meteor and to the temperature and density of the air strata between the phenomenon and the observer. Finally, careful observation of the path of a remarkable meteor may lead, as it has already done in several cases, to the recovery of meteorites. The value of these material visitors from the depths of space is very greatly increased by a knowledge of their path through our atmosphere.

If one has observed an unusually bright meteor it should never be assumed that better observations will be made somewhere else and that it is not worth while reporting it. Such meteors always come unheralded and in general all too few observations reach scientific institutions where they can be studied. It is also true that

a number of observations from various stations are essential in the complete study of any great fireball.

For the ambitious amateur, who wishes to attempt more than a programme of visual observation with the unaided eye, there are three important fields open. These are all comparatively unworked at the present time. The first of these is the telescopic observation of meteors, best performed with small telescopes of large fields such as comet seekers. Here, all the information obtained concerning the meteors brighter than fifth magnitude may be extended to much fainter, and thus smaller, objects. It is unnecessary to point out the importance of this branch of meteor study.

Second, we have the direct photography of meteors which, with the modern camera and recent fast emulsions becomes entirely practical for the amateur. A direct photograph of a meteor, in addition to giving its position very accurately, makes possible a photometric study of the luminosity variations throughout the length of the path and a detailed analysis of any short period flicker or sinoidal motion. A rotating shutter in front of the camera provides an accurate velocity determination. Velocities above a certain value earmark the meteor as arriving from interstellar space.

The third field which should be mentioned is meteor spectrophotography. This, while requiring in addition to the camera a good prism of size sufficient to cover the lens, well repays the observer for the added expense by the increased scientific value of the photographs obtained. With a meteor spectrum, of which fewer than forty have yet been photographed, one can determine much concerning the chemical constitution of the meteor and in particular the physical processes by which its luminosity is produced. This is extremely important both in a consideration of the physics of the upper atmosphere and in the determination of the relation between the original masses of the meteoric particles and their visual magnitudes as they appear to us.

The writer hopes that the above remarks will indicate the very definite value of observations which are within the scope of all those really interested in meteoric problems. He will be glad to communicate with anyone who would like to attempt a definite observational programme.

P.M.M.

NOTES FROM THE DOMINION ASTROPHYSICAL OBSERVATORY

NOTES ON SPECTROSCOPIC BINARY ORBITS

By W. E. HARPER, J. A. PEARCE, R. M. PETRIE and A. MCKELLAR

The following eight binary orbits have recently been completed:

H.D. 93033 (Pe)

$\alpha\ 10^h39^m.5;\ \delta\ +46°05'$
Mag. 6.87; B8
$P = 3.063295$ days
$e = .153$
$\omega = 242°.3$
$\gamma = -11.2$ km./sec.
$K = 53.5$ km./sec.

Boss 3102 (H)

$\alpha\ 11^h44^m.5;\ \delta\ +35°29'$
Mag. 5.76; F5
$P = 32.864$ days
$e = .087$
$\omega = 223°.58$
$\gamma = -8.28$ km./sec.
$K = 37.29$ km./sec.
$T = 2{,}422{,}059.507$
$a \sin i = 16{,}787{,}000$

Boss 4217 (McK)

$\alpha\ 16^h29^m.6;\ \delta\ +30°43'$
Mag. 6.66; F0
$P = 3.39430$ days
$e = .025$
$\omega = 355°.23$
$\gamma = -16.24$ km./sec.
$K = 68.18$ km./sec.
$T = 2{,}428{,}006.493$
$a \sin i = 3{,}181{,}000$
$\dfrac{m_2{}^3 \sin^3 i}{(m_1+m_2)^2} = 0.112\odot$

Boss 4745 (Pt)

$\alpha\ 18^h40^m.7;\ \delta\ +55°26'$
Mag. 5.08; A0
$P = 9.810$ days
$e = .022$
$\omega_1 = 155°.5$
$\omega_2 = 335°.5$
$\gamma = -30.97$ km./sec.
$K = 28.10$ km./sec.
$K = 34.11$ km./sec.
$T =$ J.D. 2,427,945.341
$a_1 \sin i = 3{,}696.038$ km.
$a_2 \sin i = 4{,}486{,}544$ km.
$m_1 \sin^3 i = 0.12\odot$
$m_2 \sin^3 i = 0.10\odot$
$m_2/m_1 = 0.82$

H.D. 199081 (Pe)

α 20^{h}49^m.7; δ +44°00′
Mag. 4.68; B3
Redetermination of orbit, using Allegheny observations of 1910.
P = 2.8546 days
e = .126
ω = 51°.7
γ = −16.2 km./sec.
K_1 = 110.2 km./sec.
K_2 = 118.6 km./sec.
T = J.D. 2,418,554.816

H.D. 199081 (Pe)

Using Victoria observations of 1935
P = 2.854822 days
e = .127
ω = 66°.2
γ = −17.3 km./sec.
K_1 = 111.4 km./sec.
K_2 = 124.8 km./sec.
T = J.D. 2,427,867.376

H.D. 199081

Combined solution

P = 2.584822 days
e = .127
ω = 48°.6 / 66°.1
γ = −17.3 km./sec.
K_1 = 110.8 km./sec.
K_2 = 121.9 km./sec.
T = J.D. 2,418,554.792 / 2,427,867.376
$a_1 \sin i$ = 4,314,000 km.
$a_2 \sin i$ = 4,746,000 km.
$m_1 \sin^3 i = 1.91 \odot$
$m_2 \sin^3 i = 1.74 \odot$
Revolution of apses in 525 years.

Boss 5536 (H)

α 21^{h}28^m.9; δ +75°58′
Mag. 7.67; F0
P = 8.4455 days
e = .039
ω_1 = 12°.2
ω_2 = 192°.2
γ = −4.69 km./sec.
K_1 = 79.71 km./sec.
K_2 = 80.28 km./sec.
T = 2,417,978.327
Elements are regarded as approximate only.

MR Cygni (Pe)	H.D. 216014 (Pe)
α 21^{h}55^m.0; δ +47°30′	α 22^{h}44^m.2; δ +64°32′
Mag. 8.5; A0	Mag. 6.83; B3
P = 1.676970 days	P = 1.77476 days
e = .122	e = .034
ω_1 = 103°.2	ω_1 = 106°.3
γ = −26.0	γ = −20.6 km./sec.
K_1 = 147.0 km./sec.	K_1 = 225.3 km./sec.
K_2 = 172.9 km./sec.	K_2 = 261.2 km./sec.
T = J.D. 2,426,970.075	T = J.D. 2,424,076.621
$a_1 \sin i$ = 3,364,000 km.	$a_1 \sin i$ = 5,495,000 km.
$a_2 \sin i$ = 3,957,000 km.	$a_2 \sin i$ = 6,371,000 km.
$m_1 \sin^3 i$ = 3.01 $\odot$	$m_1 \sin^3 i$ = 11.4 $\odot$
$m_2 \sin^3 i$ = 2.56 $\odot$	$m_2 \sin^3 i$ = 9.8 $\odot$

The magnitude and spectral type are taken from the Draper Catalogue.

Besides the foregoing there are a number of other binaries more or less completed. The eclipsing star AR Aurigae α 5^{h}11^m.8, δ +33°39′ has a period of 4.1344 days with K_1 = 107 km./sec. and K_2 = 124 km./sec. approximately. To several of the old orbits also slight corrections to the periods have been made, such being possible through the lapse of time. A list of 64 of these is almost through the press and others are awaiting measurement of only a few plates.

Dominion Astrophysical Observatory,
Victoria, B.C., November, 1935.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

The Existence of Dark Celestial Bodies

A western correspondent asks for information regarding the existence of dark stars in the depths of space. Evidence that there are such bodies is obtained chiefly from double stars. As early as 1834 Bessel noticed that the proper motion of Sirius was not in a straight line but exhibited sinuosities, and six years later he found similar, but smaller, oscillations in the motion of Procyon. He suspected that these bright bodies were attended by invisible companions, and that the revolutions of the bright and dark bodies about each other caused the waves in the observed proper motions. Some years later the orbits of both the Sirius and Procyon systems were computed from the observations and the direction of the dark body from the bright one was calculated. Both of the dark companions were finally observed in the positions predicted. Of course they were not dark after all, but it was not from the light radiated from them that their existence was deduced in the first place.

In more modern times hundreds of binary stars have been discovered by the spectroscope, and in the great majority of cases the radiations from only one of the bodies reaches the observer. Reference might be made to the discovery of the planets Neptune and Pluto by their influence upon the motions of Uranus.

The New Telescope for the Lick Observatory

The report of the Lick Observatory for 1934-35 has a special interest in that it is the last by Dr. R. G. Aitken as director.

One of the chief items in it is the account of the new 20-inch Ross-type astrographic camera or photographic refractor. A grant of $65,000 for this was made to the observatory by the Carnegie Corporation of New York at its autumn meeting in 1934. Personal application had been made to President Keppel in May, 1934, and it is the largest gift to the observatory since its foundation by James Lick. This instrument is specially to carry out certain research programmes long held in mind. They include (1) a new attack

upon the problem of the rotation of the galaxy by a study of the motions of very faint stars and (2) a study of the distribution of the faint extra-galactic nebulae, to supplement similar work being done with the the Crossley reflector and at the Mount Wilson Observatory.

Early in 1935 an additional gift of $7100 was made to the observatory by a group of friends headed by Mr. John Francis Neylan of San Francisco, to provide a measuring engine, a photometer, and other auxiliary equipment.

Orders for the glass disks for the refractor were placed early in 1935 and a contract was signed with J. W. Fecker of Pittsburgh for the construction of the lens in accordance with the specifications prepared by Dr. F. E. Ross. Negotiations for the mounting, for a photometer and for other equipment are well advanced.

The plans for the telescope have been developed chiefly by Dr. W. H. Wright, the new director. In doing this a 4-inch trial lens was constructed by Mr. Fecker according to Ross's computations, and from tests with it the specifications for the 20-inch objective were prepared.

Highest Balloon Flights

In *Science Service* it is stated that the "official" height attained by the balloon manned by Captain Albert Stevens and Captain Orvil Anderson, which made its ascent on November 11 last, was 72,395 feet (13.7 miles). This was determined by the National Bureau of Standards upon calibrating the sealed meteorograph carried by the balloon. The flight was sponsored by the National Geographic Society and the U.S. Army Air Corps. This altitude is not quite a mile higher than the unofficial figure for the Soviet balloon of 1934 which crashed on descending, with the death of its crew of three. It is 11,158 feet (upwards of 2 miles) higher than the official record set in 1933 by the Settle-Fordney American flight, which was 61,237 feet. The usual instrument-carrying balloons sent aloft in the meteorological service seldom reach greater heights, but sounding balloons which carry up nothing but themselves sometimes go higher. The highest American record is 20 miles and was made in 1913. A height of 22 miles is claimed for a German balloon, but there are doubts

about these records as theoretical considerations give reason for doubting that a balloon can rise much above 19 miles. Rockets give hope of attaining greater heights.

AMATEUR TELESCOPE MAKING—*Allan Bryce in "Southern Stars"*

The well known magazine *English Mechanics* has discontinued its astronomical department which has in the past taken an honoured place in fostering the art of telescope making. For many years it was almost the only place where popular expositions of the art might be found. Wassell, Blacklock, Ellison and other well known amateurs formerly contributed articles and letters regularly, and the craft owes much to the writings of these enthusiasts and the enlightened policy of past editors in publishing such scientific matter.

The centre of gravity of the telescope making art has now, however, crossed the Atlantic, where, in contrast to *English Mechanics*, the *Scientific American* has recently increased the space devoted monthly to this international hobby, from two pages to three. The articles now appearing in this popular American journal are in the main dealing with the very advanced phases of telescope making which some of the American amateurs are experimenting with. In the June number, for instance, appears an illustration of a 12-inch primary mirror of focal ratio *f*/1 made by a San Diego amateur. This is to be a large-field camera telescope of the type recently invented by Dr. B. Schmidt of Germany, in which a large correcting lens is introduced in front of the speculum which is of spherical figure. The workable field free from coma in such a pair, when used as a camera, may be as great as 12 degrees in diameter. This bears an astonishing comparison with the field of an ordinary parabolic mirror of *f*/5, say, which has a flat field of only one-eighth of a degree in diameter. The projected 200-inch telescope, of still shorter focal length, will have a flat field of actually less than one inch diameter.

The making of an extra-short focus combination like this would tax the skill of a professional optician, but nothing seems too hard or too new for our American friends to tackle.

THINGS SEEN AWAY FROM HOME

One of the pleasures of travel is to observe the manners and customs in other lands. During the summer of 1935 my wife and I went from Montreal to Havre to Paris, where we spent ten days attending the meeting of the International Astronomical Union. Thence we proceeded to London and then, travelling by bus, we went to north Devon, Cheltenham, Macclesfield, Ripon, Newcastle-on-Tyne, Edinburgh and Glasgow. Moving thus through the country a number of interesting things met my eyes. I shall mention a few.

In Paris, London and other cities, towns and even villages the use of mantle gas lamps for outdoor illumination is still quite common while in America it is practically never seen.

PARIS.—The familiar long loaves are interesting to a Torontonian, as are also ice-carts and other wagons with bells on them.

The use of English terms seems increasing. Among them I noticed: Garden party, Sweepstake, Plum cake, Pressing, Canoe club, Week-end à Dieppe. Also in our hotel, which was a good one on the left bank, there was an "elevator", and when an impatient Anglo-Saxon pushed the button on the ground floor, in order to hasten the descent of the car from an upper story, a green sign flashed out, "Lift Coming".

ENGLAND AND SCOTLAND.—Double-decker buses are found in almost every town and the fares are very cheap. The regular buses for greater distances, carrying from twenty to thirty passengers, are numerous and give good transportation at reasonable rates. They carry both a chauffeur and a conductor, the former being in a separate compartment alongside the engine.

Near *Slough*, a sign: "Strict Baptist Chapel."

In *Wells* (Somerset): City illumination largely by electricity.

Near *Radstock* (Somerset): a real estate sign, "Plummer & Hockey."

Near *Bath*: a nursery with proprietors, "Rich and Cooling."

Cheltenham (Gloucester): many bicycles; a woman driving a motor cycle. In this city are well known baths, made fashionable by a visit in 1788 of George III and his daughters. From a prospectus astronomers may learn that the waters are good for "gastro-intes-

tinal and cardio-vascular disorders" and for "glycosuria associated with obesity."

Near *Tewkesbury* I saw ploughing by cable. A gang-plough was drawn back and forth across a field by steam engines moving along the sides.

In *Stourbridge* (Worcester): a sign, "H. J. Shirt"; also a sign, "Flint Glass Made Here". Newton is said to have purchased at Stourbridge Fair the glass prism with which he decomposed white light. Was the prism made in this Stourbridge, or was there a Stourbridge Fair in Cambridge? Perhaps someone will inform me.

In *Macclesfield,* the chief centre of silk manufacture: a sign, "Frost & Co., Silk Throwsters."

At the Macclesfield Arms at breakfast:

Waitress.—Will you have porridge?

Guest.—What kind?

Waitress.—There is only one kind.

At *Prestbury* (Cheshire): a large church lighted with candles and oil lamps.

Near *Catterick* (Yorks): a wayside shrine; quite common in Quebec but not seen in Ontario.

At *Dewsbury*: a sign, "Bespoke Tailor."

Near *Durham*: a town named, "Pity Me."

At *Blantyre* (Lanark), where is the wonderful Livingstone Memorial: a sign, "Blantyre Co-operative Society, Groceries, Fleshing." The words "flesher" for "butcher" and "fleshing" for "butcher's meat" are not used in Canada; indeed I do not find the latter word in exactly that sense in the *Shorter Oxford English Dictionary.*

In the Edinburgh *Weekly Scotsman,* August 10: "Kirkaldy's Town Hall was on Tuesday sold by public roup at the upset price of £13,500." Most Canadians would not understand "roup."

Also, in an advertisement in the same paper: "An action of multiplepoinding and exoneration has been raised in the Court of Sessions at the instance of William Findlay . . . pursuer and real raiser." This is beyond an astronomer.

In Scotland the "Glorious Twelfth" has nothing to do with the Battle of the Boyne or the G., P. and I. King William, as under-

stood in Toronto. It is August 12th, the first day of grouse shooting and it is celebrated with almost religious zeal. The bag is reported as 33½ brace, or 57 brace, not as the astronomer would give it in single units.

ERROR IN THE 1936 *Handbook*

A slight error on page 64 was noticed just too late for correction. It is stated at the top of the page that the forty stars in the table are contained within a volume of 125 cubic parsecs. This should be 524 cubic parsecs, or one star to thirteen cubic parsecs.

C.A.C.

MEETINGS OF THE SOCIETY

AT TORONTO

October 8, 1935.—The meeting was held at 8.00 p.m. in the McLennan Laboratory, University of Toronto; A. R. Hassard in the chair.

No special paper having been arranged for, the meeting was given over to reports by various members on "Summer Observations." A report on the Perseid meteors prepared by Dr. P. M. Millman was read by Mr. Collins. Dr. Millman mentioned that in spite of bad weather and a full moon, about 2,500 observations had been made. Mr. Collins then presented a report on recent observations of lunar craters. Mr. S. C. Brown mentioned that the number of useful observations reported at the meetings might be considerably increased if more members had telescopic equipment and suggested that the Amateur Telescope Makers' section, proposed some time ago, should be definitely organized. Mr. Hassard spoke briefly on the water-levels of the great lakes and also mentioned his observations of the colour of the moon during the total lunar eclipse of June.

The meeting then adjourned, and the members and their friends gathered on the University campus where a number of telescopes had been set up and an hour was spent in making observations on various interesting subjects.

October 22, 1935.—The meeting at the usual place and hour. Mr. A. R. Hassard was in the chair.

Fourteen persons were duly elected to membership in the Society:

Rev. Michael Walter Burke-Gaffney, 403 Wellington St. West, Toronto.
Mr. R. H. Combs, 46 Lauder Ave., Toronto.
Miss Edna M. Fuller, 146 Eastwood Road, Toronto.
Mr. Henry M. Hall, Toronto.
Mr. Andrew Jack, 274 William St., Peterboro, Ont.
Dr. Bill Williams, 544 Palmerston Ave., Toronto.
Mrs. M. Vohman, 745 Bloor St. West, Toronto.

The above are attached to the Toronto section, the following are members-at-large:

Mr. W. I. Barnholth, Akron Ohio.
Mr. Custer C. Baum, Carroll College, Helena, Mont.
Mr. Philip Bernstein, New Haven, Conn.
Mr. J. Hugh Pruett, Univ. of Oregon, Eugene, Ore.
Mr. Mathew Robertson, D.D.S., Indian Head, Saskatchewan.
Mr. J. M. Sturdevant, Omaha, Neb.
Mr. O. R. Young, Riverhead, New York.

Mr. Andrew Thomson of the Meteorological Service of Canada addressed the Society on "Terrestrial Atmospheric Tides," and explained the effect of

the moon on the earth's atmosphere. We are living at the bottom of a great ocean of air which exerts a tremendous pressure at the earth's surface. Records covering a period of more than 10,000 days have been used in determining the barometric tide at Toronto. This tide has its greatest value when the moon is on the zenith, its lowest when the moon is near the horizon. The average tide at Toronto is about two-thousandths of an inch. The tides from May to August are greater than those during the months from November to February, but there is no known explanation to account for this difference.

At most stations the tide occurs just after the upper transit of the moon, although at stations in the southern hemisphere there is a tendency for the tide to occur just before the transit. However, there are many exceptions to the rule; noted ones being Vancouver, B.C., and Hamburg, Germany, in the northern hemisphere, and Apia, Samoa, in the southern.

These atmospheric tides have an effect on the height of the aurora, and the time of lighting up of large meteors varies with the tide, occurring at a higher level when the tide is full. This does not, however, seem to be true if the faint meteors are included in the analysis. The tide also appears to have an effect on the diurnal variations of the compass needle, amounting to about one degree in declination.

Mr. T. H. Mason then described the small observatory which he has recently constructed at his summer home in the Muskoka district, in which he has located the 8-inch Brashear reflecting telescope lent to him by the Society.

November 5, 1935.—The meeting at the usual time and place, Mr. A. R. Hassard in the chair.

Mr. Edwin F. Bailey, Philadelphia, Pa., was duly elected to membership as a member-at-large.

Mr. W. G. Carroll, of the Meteorological Service of Canada, spoke on the earthquake observed here at 1.00 a.m. on November 1st, and explained the difficult work of the seismologist in locating the epicentre of a quake. He stated that we know more about the interiors of the stars than we do about the inner parts of our own earth. Until about fifty years ago, the opinion generally accepted was that earthquakes were local in character and that shocks could not be transmitted through the earth. To-day, using various types of seismographs to record the shocks which are transmitted both through the crust and the interior of the earth, and by analysing the graphs produced, the seismologist is able to determine the location and magnitude of the quake. Mr. Carroll expressed the opinion that there is some doubt as to whether sounds accompany earthquakes. Large quakes are generally preceded by accessory shocks, also by after-shocks, but once the major shock has relieved the strain in the rock structure, the after-shocks are not likely to cause any damage.

Mr. J. R. Gilley, B.A.Sc., Comptroller of Hart House, University of Toronto, then addressed the meeting on "This Question of Calendar Reform," in which he presented an historical outline of the calendar from early times,

its defects, and the plans for revision. (The paper, in full, published in the JOURNAL, see page 343.)

November 19, 1935.—The meeting was held at the usual time and place, Mr. A. R. Hassard, K.C., in the chair.

Two persons were elected into the Society as members-at-large:

Mr. Clyde L. Ferguson, Charleston, West Virginia.

Mr. J. M. Holcomb, Burlington, Vermont.

Dr. Frank S. Hogg, of the David Dunlap Observatory, then spoke on "New, or Temporary, Stars." The earliest star catalogues, which were constructed to provide a check on new stars, show all the naked eye stars known to-day, with the possible exception of P Cygni. While in early times the distinction between comets and novae was so very vague that we have no real history of temporary stars previous to 146 B.C., the first mention of what was apparently a nova occurs in Chinese records about 3760 B.C. The first really scientific observation of a new star was that of Tycho's nova in Cassiopeia in 1572. The most recent is Nova Herculis, 1934, which in a period of two or three days increased its light 160,000 times from magnitude 14.5 to 1.5. As we get farther from the Milky Way the possibility of occurrence of novae becomes less. Tycho realized that there was a connection between novae and our galaxy, or Milky Way. All the other galaxies, or spiral nebulae, which have been sufficiently examined, show novae of their own. It has been estimated that the number in our galaxy would be about twenty-five of magnitude 9 or brighter, each year, of which one would be a naked-eye star. It would appear that we are missing most of these. The maintenance of a watch for such novae is a task of definite value which could be done by amateur astronomers. If all stars behaved normally, each should be a nova once every 400-million years. Geologists tell us that the age of the oldest rocks in the earth's crust exceeds 2,000-million years. The sun then is at least five times overdue to burst out as a nova. It would seem that some stars are particularly fitted for "blowing up"; others are not. Fortunately for us our sun does not seem to be gifted in this way.

While the irregularities in the light curve differ from star to star, the general trend in novae is the same, and wide, bright lines are the distinguishing feature of their spectra. The latter phenomenon is caused by the outer layers of the exploding star producing a sort of nebulous shell which causes a Doppler effect. The velocity of the expanding gas finally slows down and becomes an ordinary gaseous nebula around the star. Emission lines in the early stages of the nova are caused by a temperature increase from 9,000 degrees to more than 100,000 degrees Centigrade.

As well as normal novae, there is evidence for the existence of very bright novae, or supernovae. It has been suggested that these very hot objects might be the source of the phenomenon of such current interest, known as cosmic rays.

FREDERIC L. TROYER, *Recording Secretary.*

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